

# The flavour asymmetry and quark-antiquark asymmetry in the $\Sigma^+$ -sea

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The sea quark content of the  $\Sigma^+$  baryon is investigated using light-cone baryon-meson fluctuation model suggested by Brodsky and Ma. It is found that the  $\Sigma^+$  sea is flavour asymmetric ( $\bar{d} > \bar{u} > \bar{s}$ ) and quark-antiquark asymmetric ( $q \neq \bar{q}$ ). Our prediction for the flavour asymmetry,  $\bar{d} > \bar{u} > \bar{s}$ , is significantly different from the  $SU(3)$  prediction ( $\bar{d} < \bar{u} < \bar{s}$ ), while our prediction for the  $d\bar{d}$  asymmetry is consistent with the  $SU(3)$  prediction.

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The nucleon sea exhibits two interesting properties: flavour asymmetry [1–4] and quark-antiquark asymmetry [5,6]. While there have been many studies of the nucleon sea from both experiment (see e. g. [1–6]) and theory (see e. g. [7–11] and references therein), the studies of the sea distributions of the other baryons in the baryon octet predicted by the  $SU(3)$  quark model are very few. It is of interest to know whether the sea of the other members of the baryon octet has the same properties (flavour asymmetry and quark-antiquark asymmetry) as the nucleon sea. Also, through the study of the quark sea of the other members of the baryon octet, we can improve our understanding of the structure of the baryons and the non-perturbative properties of QCD. Alberg *et al.* [14] pointed out that the valence and sea quark distributions of the  $\Sigma^\pm$  may exhibit large deviations from the  $SU(3)$  predictions, and these parton distributions could be obtained from Drell-Yan experiments using charged hyperon beams on proton and deuteron targets. Alberg, Falter, and Henley [15] studied the flavour asymmetry in the  $\Sigma^+$  sea employing the meson cloud model and effective Lagrangian for the baryon-meson-baryon interaction, and found large deviations from  $SU(3)$ . Boros and Thomas [16] calculated the quark distributions of  $\Lambda$  and  $\Sigma^\pm$  employing the MIT bag model. It was found that the valence quark distributions are quite different from the  $SU(3)$  predictions and that the quark sea is flavour asymmetric. More recently, Ma, Schmidt and Yang [17] showed that there are significant differences between the predictions of perturbative QCD and  $SU(6)$  quark-diquark model for the flavor and spin structure of the  $\Lambda$  baryon's quark distributions near  $x = 1$ .

In this letter we shall investigate the flavour asymmetry and quark-antiquark asymmetry of the  $\Sigma^+$  sea using the light-cone baryon-meson fluctuation model (LCM) suggested by Brodsky and Ma [12]. The baryon-meson fluctuation (meson cloud) mechanism is very successful in understanding on the flavour asymmetry and quark-antiquark asymmetry of nucleon sea. The various fluctuations can be described via corresponding baryon-meson-nucleon Lagrangians [7–10]. Recently, Brodsky and Ma [12] proposed that the baryon-meson fluctuation could be described by using a light-cone two body wave function which is a function of the invariant mass squared of the baryon-meson Fock state. Compared to

the commonly used effective Lagrangian method (ELM) [7–10] for the description of baryon-meson fluctuations, the LCM is relatively simple. Furthermore our study [13] showed that the LCM can produce very similar results to the effective Lagrangian method for a suitable choice of parameter.

The basic idea of the meson cloud model (for recent reviews see Refs. [9,10]) is that the nucleon can be viewed as a bare nucleon surrounded by a mesonic cloud. The nucleon wave function can be expressed in terms of bare nucleon and virtual baryon-meson Fock states. Although this model was developed mainly in the study of nucleon sea, applying this model to the other baryons is straightforward. For the  $\Sigma^+$ , the wave function can be written as

$$|\Sigma^+\rangle_{\text{physical}} = Z|\Sigma^+\rangle_{\text{bare}} + \sum_{BM} \int dy d^2\mathbf{k}_\perp \phi_{BM}(y, k_\perp^2) |B(y, \mathbf{k}_\perp); M(1-y, -\mathbf{k}_\perp)\rangle, \quad (1)$$

where  $Z$  is the wave function renormalization constant,  $\phi_{BM}(y, k_\perp^2)$  is the wave function of Fock state containing a baryon ( $B = \Lambda, \Sigma^0, \Sigma^+, p$ ) with longitudinal momentum fraction  $y$ , transverse momentum  $\mathbf{k}_\perp$ , and a meson ( $M = \pi^+, \pi^0, \bar{K}^0$ ) with momentum fraction  $1-y$ , transverse momentum  $-\mathbf{k}_\perp$ . Here we consider the most energetically-favoured fluctuations in the baryon octet and meson octet. The fluctuation  $\Sigma^+ \rightarrow \Xi^0 K^+$  is neglected due to the higher mass of  $\Xi^0$  ( $m_\Xi = 1.32$  GeV while  $m_\Lambda = 1.12$  GeV,  $m_\Sigma = 1.19$  GeV).

It would seem that the fluctuation  $\Sigma^+ \rightarrow \Sigma^+ \eta$  is also important in the calculations of  $\bar{d} - \bar{s}$  and  $\bar{u} - \bar{s}$ . However, applying the common  $\eta_8$ - $\eta_1$  mixing scheme

$$\eta = \cos\theta \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s}) - \sin\theta \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s}) \quad (2)$$

and assuming  $SU(3)$  symmetry for the quark distributions in the  $\eta_8$  and  $\eta_1$ , we find that compared to the fluctuation  $\Sigma^+ \rightarrow \Lambda\pi^+$ , the contributions to the  $\bar{d} - \bar{s}$  and  $\bar{u} - \bar{s}$  from the fluctuation  $\Sigma^+ \rightarrow \Sigma^+ \eta$  are suppressed by a factor of  $(\frac{1}{\sqrt{6}}\cos\theta - \frac{1}{\sqrt{3}}\sin\theta)^2 - (\frac{2}{\sqrt{6}}\cos\theta + \frac{1}{\sqrt{3}}\sin\theta)^2$  which is in the range of  $-0.20 \sim -0.01$  for mixing angle in the theoretically accepted range  $\theta = -12^\circ \sim -20^\circ$  [18–22]. The higher mass of the  $\eta$  ( $m_\eta = 0.547$  GeV,  $m_\pi = 0.139$  GeV) also suppresses the contribution from this fluctuation. Thus we neglect this fluctuation in our calculation.

Provided that the lifetime of a virtual baryon-meson Fock state is much longer than the strong interaction time in the Drell-Yan process, the contribution from the virtual baryon-meson Fock states to the quark and anti-quark sea of  $\Sigma^+$  can be written as convolutions

$$q(x) = \sum_{BM} \left[ \int_x^1 \frac{dy}{y} f_{BM}(y) q^B\left(\frac{x}{y}\right) + \int_x^1 \frac{dy}{y} f_{MB}(1-y) q^M\left(\frac{x}{y}\right) \right], \quad (3)$$

$$\bar{q}(x) = \sum_{BM} \int_x^1 \frac{dy}{y} f_{MB}(1-y) \bar{q}^M\left(\frac{x}{y}\right), \quad (4)$$

where  $f_{BM}(y) = f_{MB}(1-y)$  is fluctuation function which gives the probability for the  $\Sigma^+$  to fluctuate into a virtual  $BM$  state

$$f_{BM}(y) = \int_0^\infty dk_\perp^2 \left| \phi_{BM}(y, k_\perp^2) \right|^2. \quad (5)$$

A common practice in the evaluation of the wave function  $\phi_{BM}(y, \mathbf{k}_\perp^2)$  is to employ time-ordered perturbative theory in the infinite momentum frame and the effective meson-baryon-nucleon interaction Lagrangian [7–10]. On the other hand, Brodsky and Ma [12] suggested that this wave function can also be described by using light-cone two-body wave function which is a function of the the invariant mass squared of the baryon-meson Fock state

$$\phi_{BM}(y, \mathbf{k}_\perp) = A \exp \left[ \frac{1}{8\alpha^2} \left( \frac{m_B^2 + \mathbf{k}_\perp^2}{y} + \frac{m_M^2 + \mathbf{k}_\perp^2}{1-y} \right) \right], \quad (6)$$

where  $\alpha$  is a phenomenological parameter which determines the shape of the fluctuation function. Compared to the effective Lagrangian method, Eq. (6) is quite simple. Furthermore, our study on the  $s$ - $\bar{s}$  asymmetry in the nucleon sea [13] showed that Eq. (6) can provide similar results to the effective Lagrangian method for  $\alpha = 1.0$  GeV. Because the spin structure of the baryon-meson-baryon vertex is the same for all members of the baryon octet (ignoring fluctuations to decuplet baryons), we might expect that the value of  $\alpha$  should be similar for all the members of the baryon octet. We will use  $\alpha = 0.3$  GeV and 1.0 GeV in our calculation as there is little constraint from experimental data or theoretical studies on the  $\Sigma$  sea. The normalization  $A$  in Eq. (6) can be determined by the probability for the

corresponding fluctuation. We adopt the result given in Ref. [16] for the probabilities of the various fluctuations<sup>3</sup>:

$$P_{\Lambda\pi^+} = 3.2\%, \quad P_{p\bar{K}^0} = 0.4\%, \quad (7)$$

$$P_{\Sigma^0\pi^+} = P_{\Sigma^+\pi^0} = \frac{1}{2}P_{\Sigma\pi} = 1.85\%. \quad (8)$$

In the baryon-meson fluctuation model, the non-perturbative contributions to the quark and the anti-quark distributions in the  $\Sigma^+$  sea come from the quarks and anti-quarks of the baryons ( $\Lambda$ ,  $\Sigma^+$ ,  $\Sigma^0$  and  $p$ ) and mesons ( $\pi^+$ ,  $\pi^0$  and  $\bar{K}^0$ ) in the virtual baryon-meson Fock states. So we need the parton distributions of the involved baryons and mesons as input. For the parton distribution in the pion, we employ the parameterization given by Glück, Reya, and Stratmann (GRS98) [23] and we neglect the sea content in the meson, that is,

$$\bar{d}^{\pi^+} = u^{\pi^+} = \bar{u}^{\pi^-} = d^{\pi^-} = \frac{1}{2}v^\pi, \quad (9)$$

$$\bar{u}^{\pi^0} = u^{\pi^0} = \bar{d}^{\pi^0} = d^{\pi^0} = \frac{1}{4}v^\pi, \quad (10)$$

$$v^\pi(x, \mu_{\text{NLO}}^2) = 1.052x^{-0.495}(1 + 0.357\sqrt{x})(1 - x)^{0.365}, \quad (11)$$

at scale  $\mu_{\text{NLO}}^2 = 0.34 \text{ GeV}^2$ . For the  $\bar{d}$  distribution in the  $\bar{K}^0$  we relate it to the  $u$  distribution in the  $K^+$  which are given in the GRS98 parameterization [23] also

$$\bar{d}^{\bar{K}^0}(x, \mu_{\text{NLO}}^2) = u^{K^+}(x, \mu_{\text{NLO}}^2) = 0.540(1 - x)^{0.17}v^\pi(x, \mu_{\text{NLO}}^2), \quad (12)$$

at scale  $\mu_{\text{NLO}}^2 = 0.34 \text{ GeV}^2$ .

In order to investigate the quark-antiquark asymmetry via  $d(x) - \bar{d}(x)$  in the  $\Sigma^+$  sea, we also need to know the  $d$ -quark distribution in the  $\Lambda$ ,  $\Sigma^+$  and  $p$ , for which we use the parameterization for the  $d$  quark distribution in the proton given by Glück, Reya, and Vogt (GRV98) [24],

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<sup>3</sup>Note the relationship between the fluctuation functions for various isospin states:  $f_{\Sigma^0\pi^+} = f_{\Sigma^+\pi^0}$  and the fluctuation functions given in Ref. [16] for a given type of fluctuation are defined as the sum of all isospin states:  $f_{\Sigma\pi} = f_{\Sigma^0\pi^+} + f_{\Sigma^+\pi^0}$ .

$$d^p(x, \mu_{\text{NLO}}^2) = 0.400 x^{-0.57} (1-x)^{4.09} (1+18.2x), \quad (13)$$

at scale  $\mu_{\text{NLO}}^2 = 0.40 \text{ GeV}^2$ .

We evolve the distributions to the scale  $Q^2 = 4 \text{ GeV}^2$  using the program of Miyama and Kumano [25] in which the evolution equation is solved numerically in a brute-force method. We found that at  $Q^2 = 4 \text{ GeV}^2$  all parton distributions  $v^\pi(x, Q^2)$ ,  $\bar{d}^{\bar{K}^0}(x, Q^2)$  and  $d^p(x, Q^2)$  can be parameterized using the following form

$$q(x, Q^2) = a x^b (1-x)^c (1 + d\sqrt{x} + e x) \quad (14)$$

with the parameters given in Table 1. We estimate the uncertainty in solving the evolution equations numerically and parameterizing the parton distribution in the form of Eq. (14) to be about 2% in the  $x$ -region which we are interested in *i.e.*  $x > 10^{-3}$ . The effect of evolution from a lower scale to a higher scale is to make the parton distribution more concentrated in the small  $x$  region. Thus we may expect that the  $x$  position at which an asymmetry exhibits a maximum will move to smaller  $x$  as we evolve to higher values of  $Q^2$ . However, we do not expect the asymmetry to “evolve away” at a higher  $Q^2$  scale if it exists at a lower scale such as  $\mu_{\text{NLO}}^2$ .

We investigate the flavour asymmetry in the  $\Sigma^+$  sea through calculating the differences between the antiquark distributions:  $x[\bar{d}(x) - \bar{u}(x)]$ ,  $x[\bar{d}(x) - \bar{s}(x)]$  and  $x[\bar{u}(x) - \bar{s}(x)]$  which are given by

$$\begin{aligned} x [\bar{d}(x) - \bar{u}(x)] &= x [\bar{d}_{\Lambda\pi^+}(x) + \bar{d}_{\Sigma^0\pi^+}(x) + \bar{d}_{p\bar{K}^0}(x)] \\ &= \int_x^1 dy \frac{x}{y} \left[ f_{\Lambda\pi^+}(1-y) \bar{d}^{\pi^+}\left(\frac{x}{y}\right) + f_{\Sigma^0\pi^+}(1-y) \bar{d}^{\pi^+}\left(\frac{x}{y}\right) \right. \\ &\quad \left. + f_{p\bar{K}^0}(1-y) \bar{d}^{\bar{K}^0}\left(\frac{x}{y}\right) \right], \end{aligned} \quad (15)$$

$$\begin{aligned} x [\bar{d}(x) - \bar{s}(x)] &= x [\bar{d}_{\Lambda\pi^+}(x) + \bar{d}_{\Sigma^0\pi^+}(x) + \bar{d}_{\Sigma^+\pi^0}(x) + \bar{d}_{p\bar{K}^0}(x)] \\ &= \int_x^1 dy \frac{x}{y} \left[ f_{\Lambda\pi^+}(1-y) \bar{d}^{\pi^+}\left(\frac{x}{y}\right) + f_{\Sigma^0\pi^+}(1-y) \bar{d}^{\pi^+}\left(\frac{x}{y}\right) \right. \\ &\quad \left. + f_{\Sigma^+\pi^0}(1-y) \bar{d}^{\pi^0}\left(\frac{x}{y}\right) + f_{p\bar{K}^0}(1-y) \bar{d}^{\bar{K}^0}\left(\frac{x}{y}\right) \right], \end{aligned} \quad (16)$$

$$\begin{aligned}
x [\bar{u}(x) - \bar{s}(x)] &= x \bar{d}_{\Sigma^+\pi^0}(x) \\
&= \int_x^1 dy \frac{x}{y} f_{\Sigma^+\pi^0}(1-y) \bar{d}^{\pi^0}\left(\frac{x}{y}\right).
\end{aligned} \tag{17}$$

$x[\bar{u}(x) - \bar{s}(x)]$  comes from only fluctuation  $\Sigma^+ \rightarrow \Sigma^+\pi^0$ , while  $x[\bar{d}(x) - \bar{u}(x)]$  and  $x[\bar{d}(x) - \bar{s}(x)]$  come from also  $\Sigma^+ \rightarrow \Lambda\pi^+$ ,  $\Sigma^+ \rightarrow \Sigma^0\pi^+$  as well as  $\Sigma^+ \rightarrow p\bar{K}^0$ . In Fig. 1 we present our results for  $x[\bar{d}(x) - \bar{u}(x)]$  at the scales  $\mu_{\text{NLO}}^2 = 0.34 \text{ GeV}^2$  and  $Q^2 = 4 \text{ GeV}^2$  with  $\alpha = 0.3 \text{ GeV}$ . It can be found that the contribution from the fluctuation  $\Sigma^+ \rightarrow \Lambda\pi^+$  is about twice as large as that from  $\Sigma^+ \rightarrow \Sigma^0\pi^+$ , and both are much larger than the contribution from  $\Sigma^+ \rightarrow p\bar{K}^0$ . Under evolution the distributions move from larger  $x$  to smaller  $x$  – the  $x$  position at which  $x[\bar{d}(x) - \bar{u}(x)]$  exhibits a maximum shifts from about 0.1 to 0.06 and the maximum decreases about 20%, which coincides with our naive expectation. The numerical results for  $x[\bar{d}(x) - \bar{u}(x)]$ ,  $x[\bar{d}(x) - \bar{s}(x)]$  and  $x[\bar{u}(x) - \bar{s}(x)]$  at  $Q^2 = 4 \text{ GeV}^2$  are given in Figs. 2 and 3 for  $\alpha = 0.3 \text{ GeV}$  and  $1.0 \text{ GeV}$  respectively. We can see that  $\bar{d}(x) > \bar{u}(x) > \bar{s}(x)$ , that is the anti-quark distribution in the  $\Sigma^+$  sea is flavour asymmetric.

As is well known, the nucleon sea is also asymmetric and for the proton sea  $\bar{d} > \bar{u} > \bar{s}$  [7–11]. The main difference between the proton( $uud$ ) and  $\Sigma^+(uus)$  is the replacement of a valance  $d$  quark by a valance  $s$  quark. Thus one may expect from  $SU(3)$  symmetry that the  $\Sigma^+(uus)$  sea to be  $\bar{s} > \bar{u} > \bar{d}$ . This prediction is opposite to our above conclusion ( $\bar{d} > \bar{u} > \bar{s}$ ) from the light-cone baryon-meson fluctuation model. If the  $SU(3)$  symmetry breaking in the  $\bar{u}$ ,  $\bar{d}$  and  $\bar{s}$  distributions in the  $\Sigma^+$  sea has the same source as that for the  $u$ ,  $d$ , and  $s$  quark masses, we may expect that  $x[\bar{d}(x) - \bar{u}(x)] < x[\bar{u}(x) - \bar{s}(x)]$  since the mass difference between the  $u$  and  $d$  quarks is far smaller than that between the  $u$  and  $s$  quarks. However, our calculations (see Figs. 2 and 3) show that  $x[\bar{d}(x) - \bar{s}(x)] > x[\bar{d}(x) - \bar{u}(x)] > x[\bar{u}(x) - \bar{s}(x)]$ . The relation  $x[\bar{d}(x) - \bar{u}(x)] > x[\bar{u}(x) - \bar{s}(x)]$  is opposite to our above argument, which implies that the dynamics responsible for the  $SU(3)$  symmetry breaking in the quark distributions of the  $\Sigma^+$  sea, as calculated in our model, are different from that responsible for the mass differences among the  $u$ ,  $d$  and  $s$  quarks.

Another interesting question concerning the  $\Sigma^+$  sea is the quark-antiquark asymmetry. Although the perturbative sea created from gluon-splitting is symmetric  $q = \bar{q}$  (in the leading

twist approximation in perturbative calculation), the non-perturbative sea, which may exist over a long time and has a strong connection with the “bare”  $\Sigma^+$ , may be asymmetric  $q \neq \bar{q}$ . Because of the existence of valance  $u$  and  $s$  quarks in the  $\Sigma^+$ , it is difficult to measure the differences  $u - \bar{u}$  and  $s - \bar{s}$  in the  $\Sigma^+$  sea. The most likely experiment is to measure the difference between  $d$  and  $\bar{d}$ . From the baryon-meson fluctuation model the  $d(x) - \bar{d}(x)$  turns out to be:

$$\begin{aligned}
d(x) - \bar{d}(x) &= d_{\Lambda\pi^+}(x) - \bar{d}_{\Lambda\pi^+}(x) + d_{\Sigma^0\pi^+}(x) - \bar{d}_{\Sigma^0\pi^+}(x) + d_{p\bar{K}^0}(x) - \bar{d}_{p\bar{K}^0}(x) \\
&= \int_x^1 \frac{dy}{y} \left\{ \left[ f_{\Lambda\pi^+}(y) + f_{\Sigma^0\pi^+}(y) + f_{p\bar{K}^0}(1-y) \right] d^p\left(\frac{x}{y}\right) \right. \\
&\quad \left. - \left[ f_{\Lambda\pi^+}(1-y) + f_{\Sigma^0\pi^+}(1-y) \right] \bar{d}^{\pi^+}\left(\frac{x}{y}\right) \right. \\
&\quad \left. - f_{p\bar{K}^0}(1-y) \bar{d}^{\bar{K}^0}\left(\frac{x}{y}\right) \right\}. \tag{18}
\end{aligned}$$

The numerical results at scales  $\mu_{\text{NLO}}^2$  and  $Q^2 = 4 \text{ GeV}^2$  are presented in Fig. 4. Once again one can find that evolution “pushes” the distributions to the small  $x$  region. It can be seen that  $d \neq \bar{d}$  in the  $\Sigma^+$  sea. However, the prediction for the behavior of  $d(x) - \bar{d}(x)$  depends strongly on the value of  $\alpha$  – for  $\alpha = 0.3 \text{ GeV}$   $d(x) < \bar{d}(x)$  in the smaller  $x$  region and  $d(x) > \bar{d}(x)$  in the larger  $x$  region, while for the  $\alpha = 1.0 \text{ GeV}$   $d(x) > \bar{d}(x)$  in the smaller  $x$  region and  $d(x) < \bar{d}(x)$  in the larger  $x$  region. This result is similar to our earlier finding on the  $s(x) - \bar{s}(x)$  in the nucleon sea [13] employing the same light-cone baryon-meson fluctuation model, which suggests that  $SU(3)$  symmetry in the sea holds in this case.

We turn to the discussion about  $\alpha$ -dependence in our calculation. Comparing Figs. 2 and 3 one can find that for the  $x[\bar{d}(x) - \bar{u}(x)]$ ,  $x[\bar{d}(x) - \bar{s}(x)]$  and  $x[\bar{u}(x) - \bar{s}(x)]$  the shape and maximum of asymmetries are very similar for different  $\alpha$ , while the  $x$  position at which the asymmetries exhibit maxima shifts slightly. The calculations with  $\alpha = 0.3 \text{ GeV}$  peak at about  $x \simeq 0.06$  while the calculations with  $\alpha = 1.0 \text{ GeV}$  peak at about  $x \simeq 0.1$ . Thus the calculations for the flavour asymmetry are not very sensitive to the value of  $\alpha$ , and  $x$  being about 0.08 is a good region to study the flavor asymmetry in the  $\Sigma^+$  sea. This observation is consistent with the prediction given in Ref. [14] – the region  $0.1 \leq x \leq 0.2$  should be a good one to measure the flavour asymmetry in the  $\Sigma$  sea. The calculation for the  $d(x) - \bar{d}(x)$



(see Fig. 4) is much more sensitive to the value of  $\alpha$  than that for the flavour asymmetry – the calculations with  $\alpha = 0.3$  GeV and 1.0 GeV even give opposite predictions for the  $x$ -dependence of  $d(x) - \bar{d}(x)$ . We may expect that further calculation [26] on the nucleon sea employing the light-cone baryon-meson fluctuation model may provide useful constraints on the value of  $\alpha$ , and thereby give more definite predictions on the sea quark content in the  $\Sigma^+$  baryon.

In summary, besides the nucleon sea the studies on the sea quark content of the other members of the baryon octet are interesting and important since it is helpful to our understanding of both the structure of the octet baryons and non-perturbative QCD effects such as  $SU(3)$  symmetry breaking and flavour asymmetry. We calculated the sea quark content of the  $\Sigma^+$  baryon employing the light-cone baryon-meson fluctuation model. It was found that the  $\Sigma^+$  sea is flavour asymmetric ( $\bar{d} > \bar{u} > \bar{s}$ ) and quark-antiquark asymmetric ( $q \neq \bar{q}$ ). Our prediction for the flavor asymmetry,  $\bar{d} > \bar{u} > \bar{s}$ , is significantly different from the  $SU(3)$  prediction ( $\bar{d} < \bar{u} < \bar{s}$ ), while our prediction for the  $d-\bar{d}$  asymmetry is consistent with the  $SU(3)$  prediction.

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Table 1. Parameters in Eq. (14) at  $Q^2 = 4 \text{ GeV}^2$ .

	$a$	$b$	$c$	$d$	$e$
$v^\pi(x, Q^2)$	1.712	-0.518	1.182	-0.836	0.972
$\bar{d}^{\bar{K}^0}(x, Q^2)$	0.910	-0.519	1.418	-0.910	1.086
$d^p(x, Q^2)$	0.615	-0.575	5.096	1.102	6.773

## FIGURE CAPTIONS

Fig. 1.  $x[\bar{d}(x) - \bar{u}(x)]$  with  $\alpha = 0.3$  GeV. The dashed, dotted, and dashed-dotted curves are the contributions from  $\Lambda\pi$ ,  $\Sigma\pi$  and  $pK$  components respectively. The solid curve is the sum of above three contributions. The thinner and thicker curves correspond to the scales  $\mu_{\text{NLO}}^2 = 0.34$  GeV<sup>2</sup> and  $Q^2 = 4$  GeV<sup>2</sup> respectively.

Fig. 2.  $x[\bar{d}(x) - \bar{u}(x)]$ ,  $x[\bar{d}(x) - \bar{s}(x)]$  and  $x[\bar{u}(x) - \bar{s}(x)]$  at  $Q^2 = 4$  GeV<sup>2</sup> and with  $\alpha = 0.3$  GeV.

Fig. 3. Same as Fig. 2 but with  $\alpha = 1.0$  GeV.

Fig. 4  $d(x) - \bar{d}(x)$  with  $\alpha = 0.3$  GeV (dashed curve) and  $\alpha = 1.0$  GeV (dotted curve). The thinner and thicker curves correspond to the scales  $\mu_{\text{NLO}}^2$  and  $Q^2 = 4$  GeV<sup>2</sup> respectively.

Fig. 1

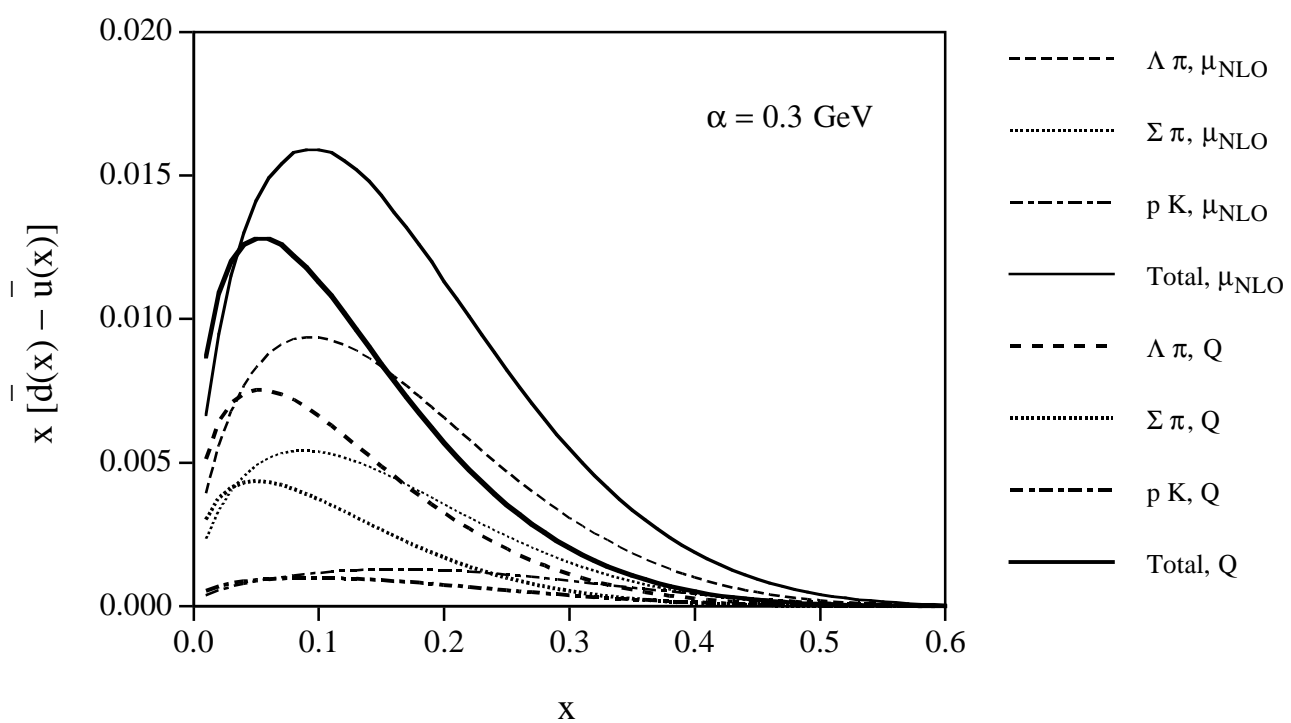


Fig. 2

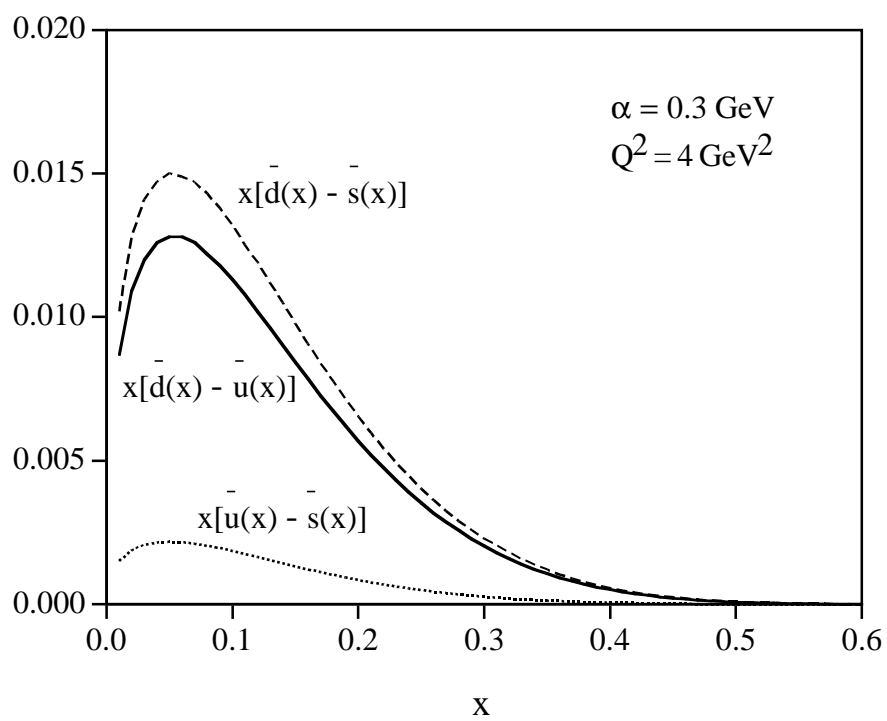


Fig. 3

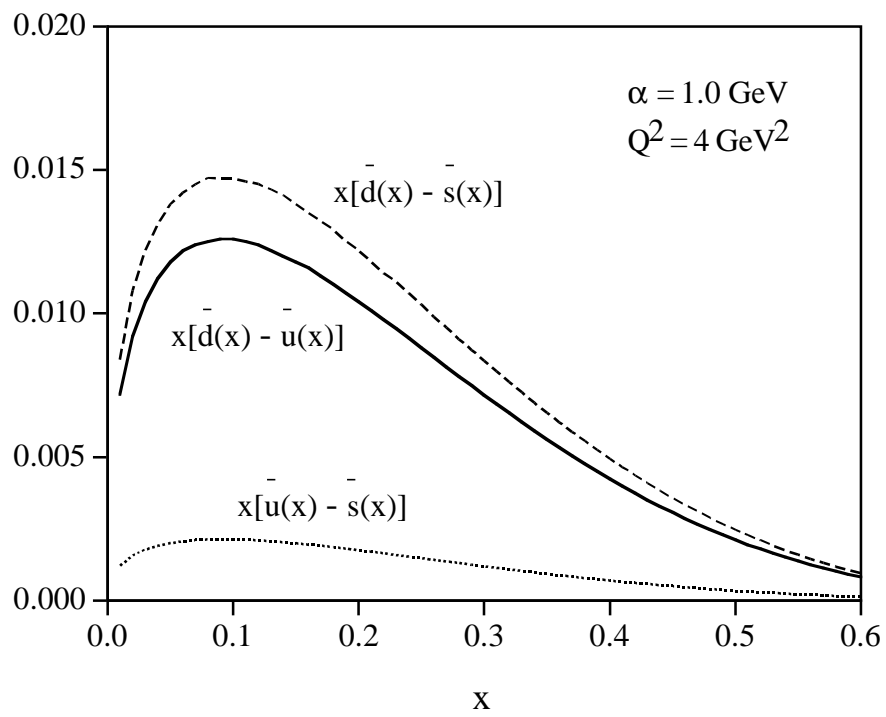




Fig. 4

